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INTEGRATED SEALING DESIGN (ISD) FOR A DOCKING ASSEMBLY USED IN OPTICS ASSEMBLY SYSTEM FOR NATIONAL IGNITION FACILITY (NIF)

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ABSTRACT

The National Ignition facility (NIF) is a high power laser facility for fusion research. The project's design philosophy modularizes the laser' optical subsystem components into Line Replaceable Units (LRU) for ease in maintenance over its expected 30 year life. The LRUs are transported between the Optics Assembly Building (OAB) and the laser structure by a robotic material handling system. A major component of part of this handling system is a portable clean room, or canister, which protects the optics of the LRU during transport between the OAB and the laser. The canister itself contains robotic systems that move the LRU into position inside the clean laser cavity, once the canister is docked to the laser's enclosure. The bottom loading canister carries a variety of different LRUs for placement in different portions of the laser. With this canister docking is accomplished from underneath the laser enclosure. A cover plate at top of the canister shall move sideway to allow the LRU to move in the enclosure. The cover plate is then move back to its original position and sealing the enclosure for maintaining the positive pressure. Each rectangular opening is 37" x 25" for the periscope enclosure. The opening is sealed by automatic operation. A floating type flanged jointed assembly using 4 mm wide flat rubber gasket. Design of enclosure for sealing pressure of 12" of water column is not included in design standards such as the ASME PVPC code and the European code EN 1591[1]. A great deal of research and development world wide on gasket testing for bolted joints are provided for sealing pressure in exceeding 400" of water column.

1. Introduction

A Bottom Loading Canister is used to move a Line replacement Unit (LRU) vertically into a clean room environment. A cover plate is used to close the pressurized enclosure with two pins for quick automatic operation. NIF automatic operation group employs an integrated sealing design (ISD) that requires controlled deformation on both the cover plate and the docking frame. A docking frame is an interface flange designed to serve as the register reference for the canister docking, as a flange for sealing the bottom of the enclosure and to serve as local sealing flange for each cover plate. Adequate thickness is required to transmit the hydrostatic load by the cover plate and the docking frame. The midpoints between the clamping joints are the vital point of this integrated sealing design. This paper presents a finite element solution for the bowing of the cover plate using the gasket as an elastic foundation to support the hydrostatic end load, clamping forces and gravity. A guideline is presented for the integrated sealing design on automatic operating docking assembly. The results of the maximum differential vertical deflections and maximum combined stresses are presented in this paper.

2. Method of Analysis For The ISD

A gasket joint may be designed according to the theory of "Beam on Elastic Foundation" [2, 3]. Similar approach of using elastic foundation as the boundary by finite element method for a deflection limit design was reported [4]. The nonlinear distribution of gasket seating pressure can be evaluated by the proposed linear elastic analysis using finite element method. Difference of the reported model [4] and the present model is that the soil is replaced by rubber as an elastic medium. Better results are expected if the behavior of the material for the foundation is a good match to the theoretical assumption. The present cover plate is modeled with the SHELL63 element of the ANSYS [5]. The elastic foundation is specified on a 4 mm width that represents the gasket seating area along the flange as shown in Fig. 1. The gasket spring constant is shown in Fig. 2. The center position of the gasket remains unchanged under sealing operation. Analysis can be performed on separate models that is the cover plate and the frame separately. The nonlinear distribution of the gasket seating stress can be calculated from the vertical deflection on the cover plate.

3. Description of The Integrated Sealing System for A Docking Assembly

The periscope enclosure bottom frame has 10 rectangular openings separated by cross beams. Each cross beam carries two 560 lbs concentrated loads in 25" apart. The maximum differential deflection (Dt) (See Equation 1) of the ISD is located in the crossbeam and to be limited to 0.0375". The height of the crossbeam is determined as a variable. The width (21.85 mm) of the crossbeam is specified as a constant. The width of the long beam (13.4 mm) is also specified as a constant. The crossbeam and the long beam forms a small rectangular flange (SRF) for the cover plate. A large rectangular flange (LRF) serves a load support for the SRF. The LRF is 28.58 mm (1.125") thickness and support 10 cover plates and serves a bolted flange to the enclosure. The LRF and the SRF form an integrated sealing unit that seal ten removable cover plates below and seal the enclosure above. It also serves as registering stations for the docking canister. The integrated sealing design requires optimizing design on the three elements, the gasket, the cover plates and the plane frame.

4. Procedure For the Integrated Sealing Design (ISD)

4.1 Gasket. The thinnest possible flat gasket is selected for the ISD used in NIF operation. A thin gasket offers advantage of fewer voids and less permeability, less distortion, reduced creep relaxation and thickness tolerances and high resistance to blowout. The thickness of the gasket is however, depending on the amount of the unevenness associates with the mating cover plate and frame warpage, flatness, and deflection under operation. A rubber gasket (COHR-R10480) is used for its low seating pressure (2 to 7 psi or 25% to 40% compression)

4.2 Cover plate. Minimizing the structural deflection (Dcp) to allow larger deflection budget for the SRF. Minimize (Dcp) by maximizing a ratio called R/W. Where R is the product of the material elastic modulus and the bending rigidity of the cover plate. W is the weight density of the plate material. The SRF should have a vertical deflection Df less than the (Dt-Dcf) for allowing warpage induced by other factors. Differential defection (Dt) is calculated from the gasket thickness (H =0.25") by the following formula:

$$Dt = (40\%-25\%)(H) = 0.0375" \qquad \text{Equation [1]}$$

4.3 The SRF, The maximum structural deflection (Df) is calculated from the pins mounting point at the cross beam to the points in the middle between the two set of pins calculated by the formula as:

$$Df = Dt - Dcp \qquad \text{Equation [2]}$$

Design of the frame to meet the deflection budget may run into thousands of options as summered by Tiszauer [6]. These options include space restriction, materials selection, welding residual stress effect, material long term dimensional stability effect, method of fabrication and manufacturing cost.

5. Loading And Bourdary Conditions

Adequate gasket seating pressure needs to be maintained within 2 to 7 psi. The cover plate is supported by pins at opposite side of the plate and mounted into a frame. Hydrostatic load is 411 lb. Gasket seating load is 89 lb. Dead weight of the cover plate is 92 lb. Total load on the elastic foundation of the cover plate is 592 lb. The downward load for the LRF is the sum of 10 SRF with 503 lb plus dead and live load on the frame. Boundary conditions for two models are a 4 mm elastic foundation supporting the 592 lb on the cover plate, and a group of 76 bolts tightened to the bottom of the enclosure to support the frame including 10 cover plates. Both the cover plate and the frame are designed for seismic safety by analysis. The results of seismic analysis is beyond the scope of this paper. Pin loads are modeled as two concentrated Loads. Uniform pressure (12" water hydrostatic pressure) is added to the surface of the cover plate and the beams. Dead load is also included.

6. Requirements for safety and Operation

6.1 For safety requirements, the maximum stress from operation condition is limited to within 33.3% of the material yield strength. The maximum seismic stress is limited to within the material yield strength.

6.2 For sealing requirement, The tightness of the joint is design to maintain 12" of water column pressure.

7. Conclusion and Recommendations

Adequate sealing requires a pin applying load accurately at 296 lb (592 lb/2) on each side of the cover plate. The cover plate is inserted to the cross beams by pins. Two options to produce the pin load. Option (1) Use of the NIF Operation Supervisor control by applying pin load by load cell with hydraulic pressure adjusted according to a load sensor. The advantage of this option is a constant 296 lb load that provides excellent sealing. Option (2) Design an oval slot in the pin inserting holeon the cross beam. Using dynamic compression limit of the rubber as 75% of the thickness, The ovlaity of the pin hole may be is:

Op = Pin hole ovality = (75%-40%) x H (Gasket thickness)

For a 19.5 mm diameter (Dd) pin as used for the enclosure design, the vertical slot length (Ls) is

Ls= Dd + Op = 19.5 mm + (0.35 x 0.25) x 25.4 = 21.723 mm

This option is less expensive but the tightness and life of the joint are inferior to option (1).

Additional deflection from residual welded joint stress, long term material dimensional instability, thermal effect and manufacturing tolerances are may add to the total deflection budget and the placement of the welded joints must be carefully examined to avoid unexpected deformations.

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REFERENCES

(1) K. Hsu, "ASME PVRC Bolted Flanged Connections Committee 1998," San Diego, CA.
(2) M. Hetenyi, "Beams on Elastic Foundation." The university of Michigan press 1936.
(3) V. Z. Vlasov et al, " Plates and shells on elastic foundations." Moskva, 1960, Russia.
(4) K. K. Leung, "An Engineering Design Study of SDC Detector Deformation for SSC Labora tory," Proceeding Supercollider 4, Plenum Press, New York., NY. (1992).
(5) ANSYS Finite Element Program, Swanson Analysis Systems Inc. 1997.
(6) D. Tiszauer, "NIF Periscope Docking Plate Design Options," Presented in the NIF Operating Group Meeting, Lawrence Livermore National laboratory, California, January 6, 1999

A cover plate of aluminum material is modeled by the ANSYS finite element code. The original design is shown below. The flange is thicker than the plate as shown in the center. Since a 0.25" flat rubber gasket is selected for the sealing joint, the rigidity of the cover plate must be increase to reduce the global plate deflection. The result is the central portion is increase to have the same thickness of the flange. 4 mm width as shown in the rim of the cover plate is the finite element incorporated with a elastic foundation option.

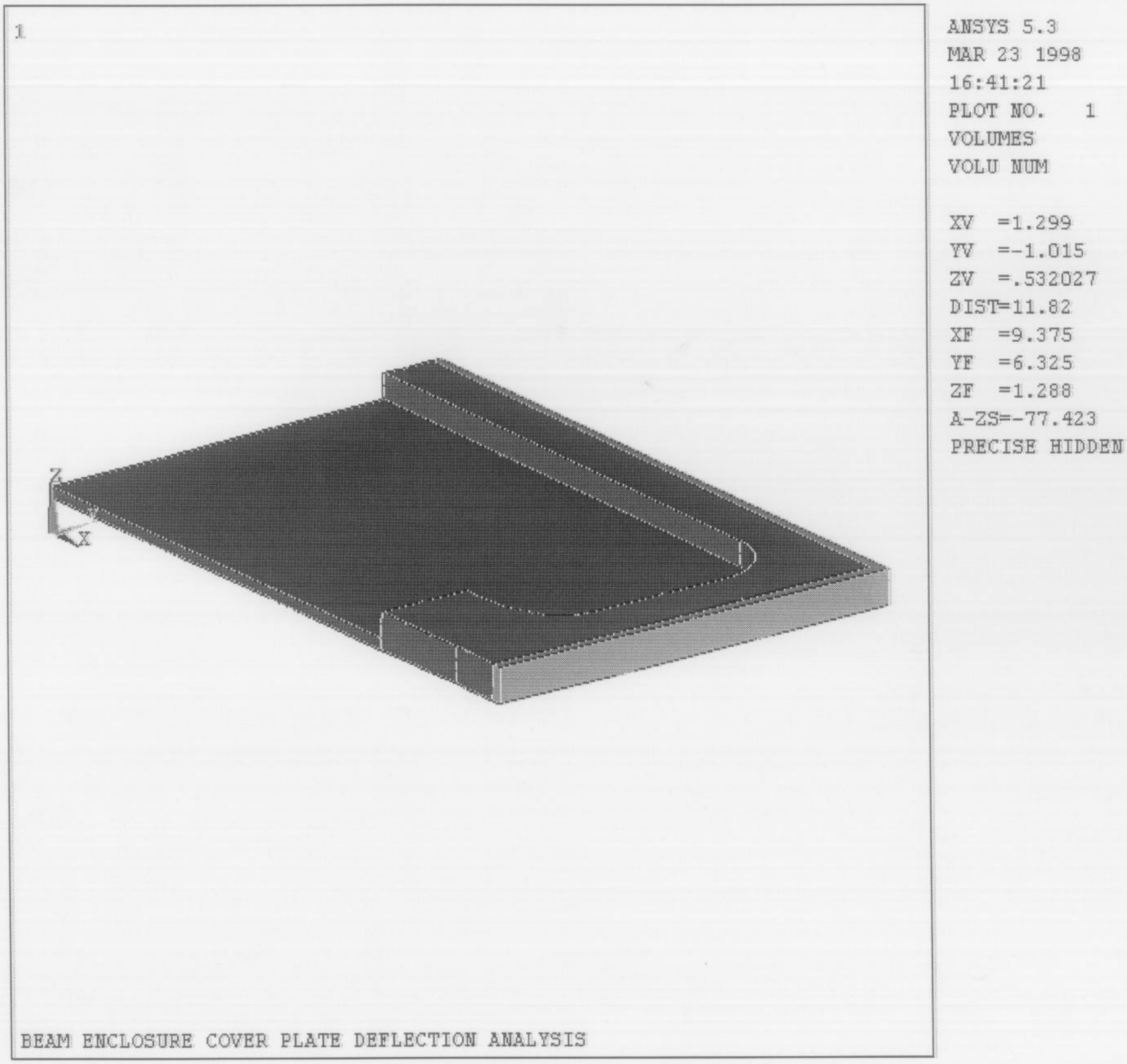

Fig.1 The Cover Plate with the Pin located at X= Xmax. and Y=0 Location
1/4 Model Is Used For Axsymmetrical Loading Condition

Fig. 2 represents the theoretical prediction of the spring of the rubber gasket. It is considered an good approximation because the rubber material and thickness is thin. However the aspect ratio of the gasket needs to be controlled to a ratio closed to 1.0. The aspect ratio is the width od the gasket subjected to compression loading divided by the height of the gasket. In the present design, the effective width is 4 mm and the gasket height is 6.35 mm and assume at 35% compression, the aspect ratio is

4 mm / 6.35 x 0.65 = 0.969

Nonlinear spring rate shall induce by high aspect ratio. Possibility of buckling instability is also increase if the aspect ratio increases over 1.0

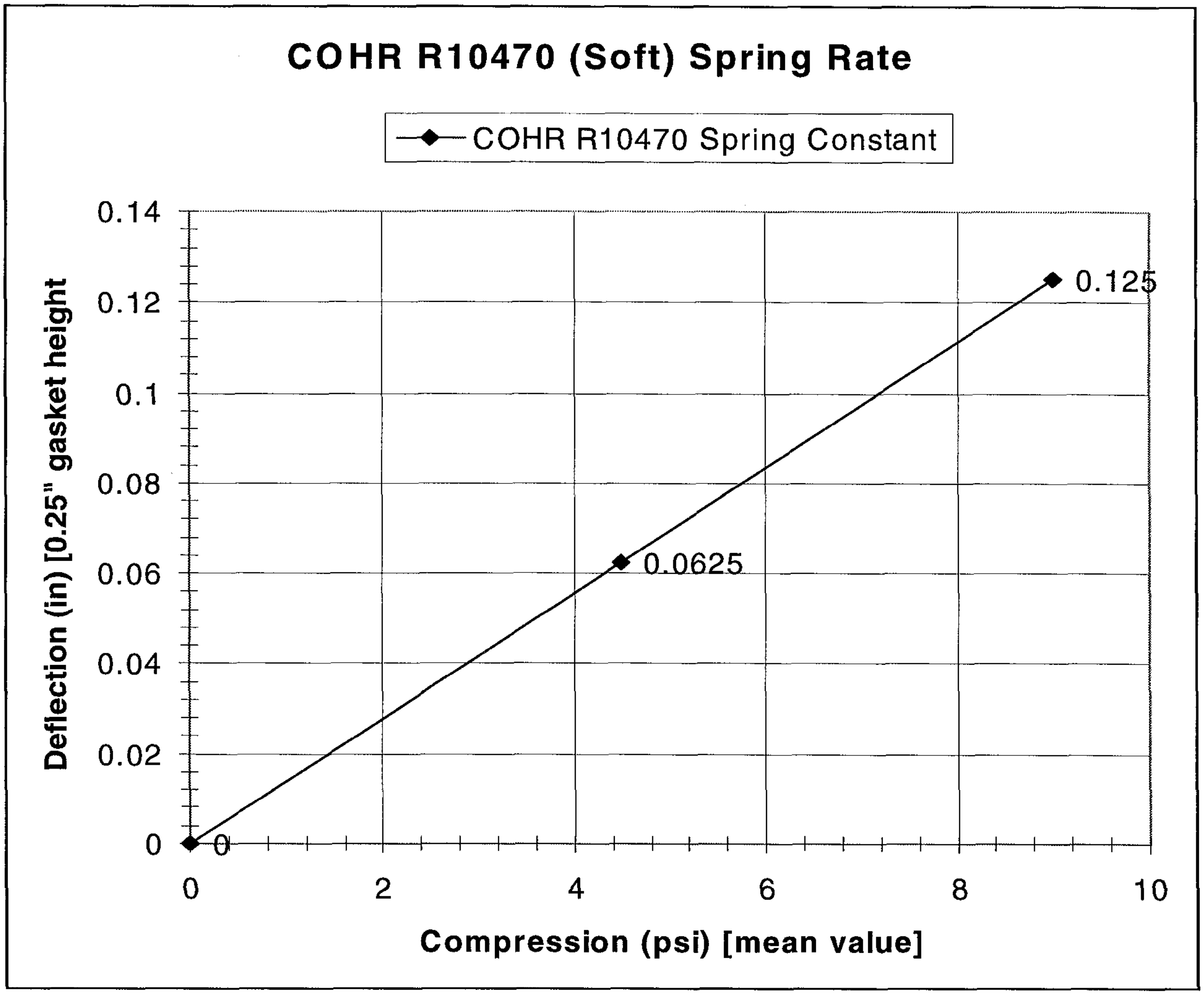

Fig.2 Spring rate of The Cover Plate Sealing Joint Calculated From A 0.25" Flat Rubber Gasket

Fig. 3 Shows the optimum design of the frame (Docking Plate) by a design that specified aluminum alloy 5083-H321 as welded condition. The 5083-H321 alluminum alloy as a plate with thickness of 1.0" to 3.0", has a minimum elastic yield strength of 23 ksi, based on the 1997 Uniform Building Code Volume 2, Table 20-II-B
(Gas Tungsten Arc or Gas Metal Arc Welding with No Postweld Heat Treatment)

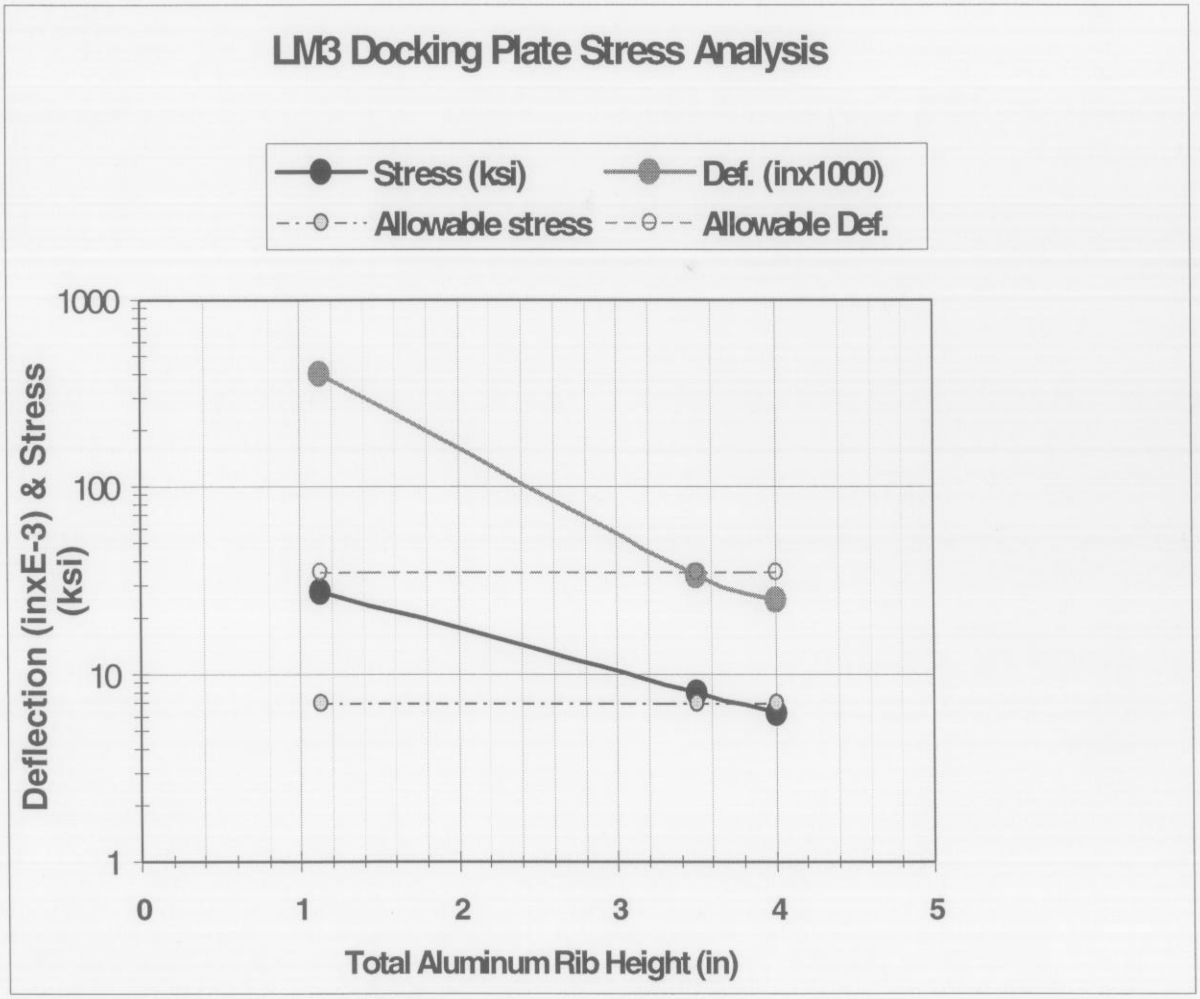

Fig.3 Design Result of The Cross Beam Reinforcement By Increasing the Height of the Rib to Gain Structural Bending Rigidity In Order To Reduce SRF deflection

Fig. 4 Shows the another optional design of the frame (Docking Plate) by a design that specified aluminum alloy 5083-H321 as welded condition. The rib height remains unchanged. The effect of reduction on the SRF is must less effective.

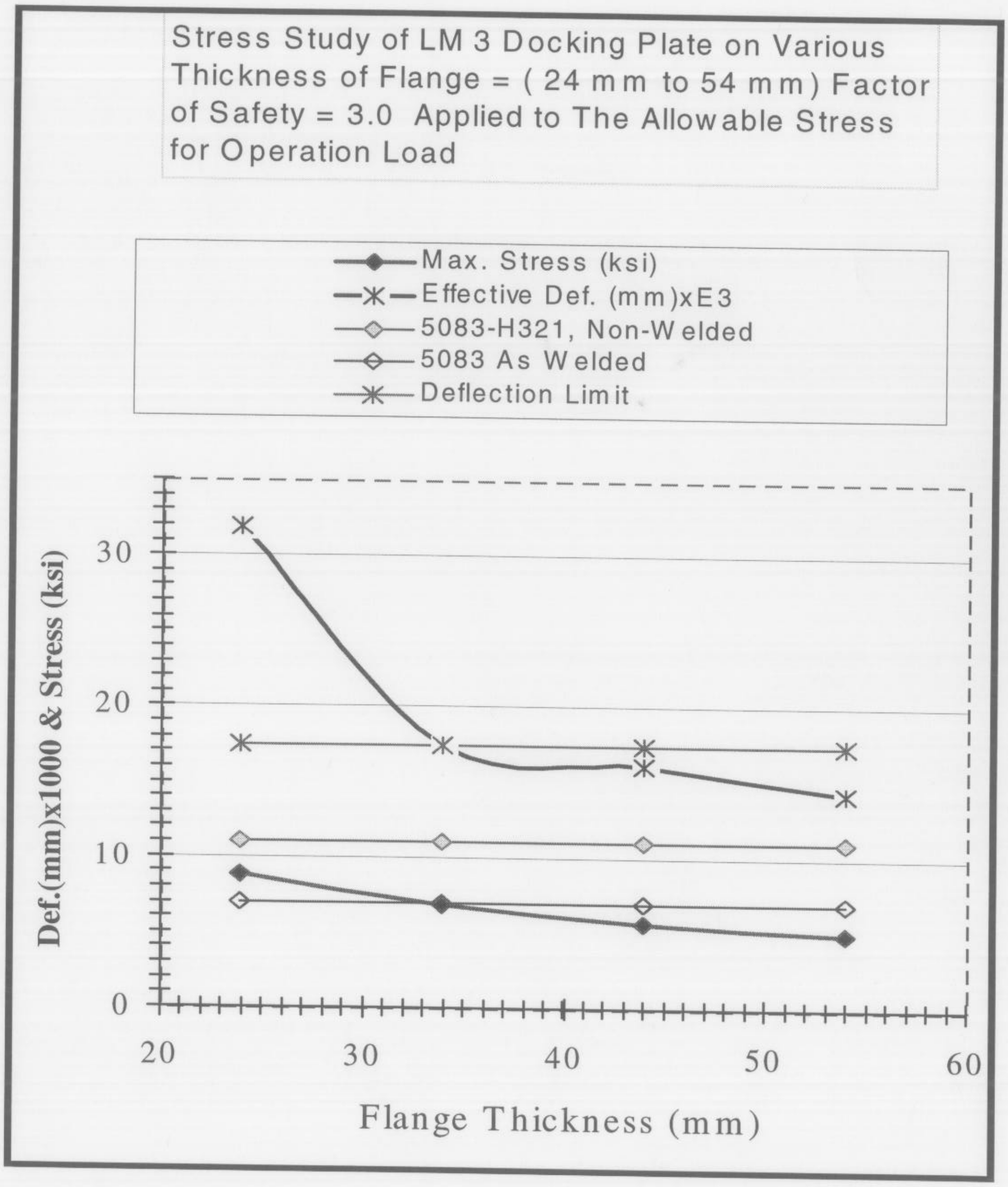

Fig. 4 Design Result of The LRF Reinforcement By Increasing the Height of the Flange to Gain Structural Bending Rigidity In Order To Reduce SRF Deflection